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Occupational cancer risk in pilots and flight attendants: current epidemiological knowledge

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Abstract Occupational studies of aircrew in civil or military aviation did not receive much attention until the beginning of this decade. Since 1990, a number of epidemiological studies has been published on the cancer risk among flight personnel. Their results are equivocal: elevated cancer risks have been observed in some studies, but not in others. The exposure situation for pilots and flight attendants is unique with respect to several factors and particularly in that cosmic rays contribute substantially to their cumulative radiation dose. The average annual doses received are relatively low, however, and commonly range between 3 and 6 mSv. Results of epidemiological studies are presented as well as information on planned studies, ozone and jet engine emissions as well as electromagnetic fields. Lifestyle factors such as irregular working hours, inadequate diet and disruptions of the circadian rhythm may furthermore play a role in their cancer risk. Cabin attendants are additionally exposed to passive smoking. So far, few epidemiological studies have been carried out to determine the mortality and cancer incidence of aircrews. This paper reviews these studies, summarises the current epidemiological knowledge on the cancer risk among flight personnel and describes planned and ongoing investigations.

Introduction

Until recently, the occupational epidemiology of flight personnel of airlines and in the military, a group of persons with specific occupational exposures, has been paid little attention. More recently, interest has increased, but a shortage of facts still remains concerning the life expectancy and causes of death among pilots and cabin crew. Commercial airline pilots and cabin crew have a unique working environment with exposure to known or suspected carcinogens or mutagens, in particular ionising radiation.

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Occupational exposure of flying personnel

Cosmic radiation

Among others, exposure to cosmic radiation is an important occupational risk factor for the group under consideration. Natural sources of radiation include radioactive substances in the earth and cosmic rays. Dose rates in the air are about 30 nSv/h at sea level for any latitude and increase to about 5–10 µSv/h at flight altitude depending on the latitude. It can reach a maximum of 19 µSv/h in times of minimal solar activities, such as occurred in 1965. Neutrons contribute significantly to the equivalent dose of cosmic radiation at flight altitudes of jet aeroplanes [1]. During the past few years, several investigations have been performed to estimate and to measure the effective equivalent dose [1–4]. In their 1988 report, UNSCEAR [2] estimated the equivalent dose-rates at an altitude of 10 000 to 12 000 m to be 10 µSv/h, of which about 30%–60% is due to neutrons. At an average altitude of 8000 m, UNSCEAR estimated the effective dose rate for commercial flights as 2 µSv/h. For German pilots flying transatlantic routes, an equivalent dose of 5.3 µSv/h was calculated by the German Radiation Protection Commission (SSK), resulting in 3.2 mSv/year for 600 flight-hours [5]. The potential annual maximum equivalent dose was estimated to be 8.3–8.7 mSv/year [5]. An exposure of 6 µSv/h was ob-

Table 1 Results of mortality studies among pilots (PMR proportional mortality ratio, SMR standardised mortality ratio, CI confidence interval, nr not reported)

	Salisbury et al. [14]			Irvine and Davies [15]			Band et al. [17]			Kaji et al. [16]			Band et al. [18]		
Study type	PMR study			PMR study			Cohort study			Cohort study			Cohort study		
Population	Male pilots in British Columbia, Canada			Male pilots British Airways			Male pilots CP Air, Canada			Male pilots Japan Airlines			Male pilots Air Canada		
Period	1950–1985			1966–12.1989			[illegible]			[illegible]			1950–1992		
Persons	Not known			Not known			[illegible]			2327			2740		
Person-years	Not known			Not known			[illegible]			[illegible]			[illegible]		
Deaths/cancer death	[illegible]			[illegible]			[illegible]			[illegible]			[illegible]		
Results	n	PMR	95% CI	n	PMR	95% CI	n	SMR	95% CI	n	SMR	95% CI	n	SMR	95% CI
All causes		nr			nr		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]–0.85	219	0.63	0.55–0.72
Aircraft accidents	[illegible]	31.44	[illegible]	[illegible]	[illegible]	[illegible]	23	[illegible]	[illegible]		nr		[illegible]	26.6	[illegible]
All cancer causes	51	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	56	0.61	[illegible]
Rectal cancer	1	0.45	[illegible]	3	[illegible]	[illegible]	3	4.25	[illegible]					nr	
Brain cancer	4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				[illegible]	1.42	[illegible]
Lung cancer	18	[illegible]	[illegible]	44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				[illegible]	0.25	[illegible]
Leukaemia		nr		[illegible]	[illegible]	[illegible]	[illegible]						[illegible]	0.86	[illegible]
Prostate		nr		10	[illegible]	[illegible]	[illegible]						[illegible]	1.52	[illegible]
Melanoma	3	2.08	[illegible]	6	6.68	[illegible]	[illegible]						2	1.49	[illegible]

[a] Myeloid leukaemia

tained by a measurement programme carried out by British Airways on board long-haul aircraft [6]. These exposures are within the range of the regulations for occupationally exposed personnel and are similar to the actual exposure due to ionising radiation that workers in nuclear power stations receive.[1] However, these levels are only slightly higher than annual exposures due to natural background radiation (about 2.4 mSv).

Other potential risk factors

Radiation exposure is not the only risk factor in the occupational environment of flight crews. Pilots are exposed to electromagnetic fields ranging from 400 Hz to several GHz, resulting in exposures ranging from 0.2 to 1.7 μT in the cabin (Nicolas et al., manuscript submitted), to ozone and to jet engine emissions including benzene [7, 8]. Diet and constipation may additionally play a role for the health of flight personnel in view of alterations in bowel transit times due to disruptions of the circadian rhythm. Cabin attendants are exposed to passive smoking [9], although more recently an increasing number of airlines have adopted a non-smoking policy. In terms of overall mortality and life expectancy, aircraft accidents are obviously a more important occupational risk for pilots and flight crews in comparison with the normal population.

[1] Current recommendations from ICRP: 100 mSv over 5 years, not exceeding 50 mSv in 1 year. German regulations: 400 mSv lifetime dose, not exceeding 50 mSv in 1 year. Estimated actual exposure in German nuclear power plants in Germany: 2.5 mSv per exposed person

Cancer risk among persons exposed to low-dose radiation

Ionising radiation has been shown to be carcinogenic to humans, although the effect at low doses is still being debated [10]. Its effect is characterised by a strong dependency on time since exposure, with leukaemias occurring early and solid tumours appearing late. Numerous occupational cohorts of nuclear workers exposed to low levels of radiation have been carried out, with inconsistent results. The IARC (International Agency for Research on Cancer) study group on cancer risk among nuclear industry workers published the results of a mortality study using data combining seven cohorts from three different countries [11, 12]. Estimates in this evaluation are very close to current radiation protection recommendations derived from extrapolation models using data from atomic bomb survivors. However, persons who work in the nuclear industry are predominantly exposed to gamma-radiation, while airline crews are exposed to cosmic radiation, of which up to 60% of the equivalent dose may be due to neutrons [2].

Mortality and cancer risk: epidemiological studies

So far, few data are available on mortality or cancer incidence of flying personnel. An early study by Hoiberg and Blood [13] showed elevated hospitalisation rates among US Navy pilots due to certain types of cancer. However, hospitalisation rates are of limited value in the assessment of morbidity or incidence rates. A potential selection bias is the good surveillance of the health status of pilots, which might lead to an increased hospitalisation rate. Thus, this study cannot be used to investigate whether cancer rates are greater among pilots.

Table 2 Results of incidence studies among pilots and cabin crew (SIR = standardized incidence ratio)

	Band et al. [17]			Band et al. [18]			Grayson and Lyons [21]			Pukkala et al. [20]		
Study type	Cohort study			Cohort study			Cohort study			Record linkage study		
Population	Male pilots, CP Air (Canada)			Male pilots, Air Canada			Male personnel US Air Force			Cabin attendants, Finnair		
Period	01/1950–10/1988			1950–1992			1975–1989			1967–1992		
Persons	913			2740			59 940[a]–167 265			1577 women, 187 men		
Person-years	18 000			62 449			1.6 Mil			22 000 women, 2500 men		
Cancer cases	57			125			342/8277			35 (women 32 men 3)		
Incidence	*n*	SIR	95% CI	*n*	SIR	95% CI	*n*	SIR	95% CI	*n*	SIR	95% CI
All cancer	57	nr		25	0.71	0.59–0.85	342	1.19	1.07–1.32	35	1.23	0.86–1.71
Rectal cancer	4	1.94	0.61–4.97	4	0.42	0.13–1.08	26[c]	1.31	0.83–2.07	2	1.32	0.16–4.75
Brain cancer	4	3.45	1.09–8.83	7	1.53	0.65–3.15	17	0.71	0.39–2.07			
Lung cancer	3	0.41	0.11–1.20	11	0.28	0.14–0.50	16	0.81	0.47–1.32	1	1.61	0.04–8.95
All leukaemias	2	nr		9	1.65	0.79–3.13	13	0.89	0.49–1.52	2	3.57	0.43–12.9
Prostate	3	3.9	1.01–11.40	34	1.87	1.30–2.61	nr					
Melanoma	3	1.5	0.39–4.47	8	1.52	0.69–3.0	49	1.50	1.11–1.98	3	2.11	0.43–6.15
Non-melanoma skin cancer	26	1.5	1.05–2.33	nr			36	1.45	1.02–2.01			
Testis	2	1.7	0.32–6.32	2	0.63	0.12–2.28	59	1.04	0.79–1.34			
Urinary bladder		nr		4	0.36	0.11–0.92	19	2.09	1.28–3.26			
Hodgkin's disease	3	4.51	1.17–15.27	nr			14	0.51	0.29–0.86			
Bone										2	1.51	1.82–54.4
Breast										20	1.87	1.15–2.23

[a] Aircrew
[b] Other officers
[c] Includes colon cancer

A small number of analytical epidemiological studies has been published. There are two reports on proportional mortality ratios (PMR) among pilots [14, 15], one registry-based study on occupation and malignant melanoma [16], several cohort studies among civil pilots [17–19], and one cohort study among cabin crews [20]. Recently, a cohort study among members of the US Air Force [21] and a set of case-control studies on brain tumours [22, 23] within this group have been published. An overview of these studies is presented in Tables 1–3.

Table 3 Results of the case-control study by Grayson in 1996 [22] *ELF* extremely low frequency, *RF* radio frequency, *MW* microwave

	Grayson [22]	
Study type	Case-control (nested)	
Disease	Brain tumour	
Population	Male personnel US Air Force	
Period	1970–1989	
Cases	230	
Controls	920	
Matching	1 case/4 controls by age, race	
Exposure assessment	Job exposure matrix, dosimetry data	
Odds ratio (OR)	OR (exposed/non-exposed)	95% CI
ELF electromagnetic fields	1.28	0.95–1.74
RF/MW electromagnetic fields	1.39	1.01–1.90
Ionizing radiation	0.58	0.22–1.52
Socioeconomic status	3.30 (senior officers vs all others)	1.99–5.45

The proportional mortality studies

In 1991, Salisbury et al. [14] reported proportional mortality rates among pilots in British Columbia. In total, 341 deaths in men whose 'usual occupation' was listed as 'pilot' were included in the analysis. The authors reported a markedly elevated risk for aircraft accidents. The risk for artherosclerotic heart disease was decreased. Cancer risks were non-significantly elevated for cancer of the colon, the brain and the nervous system as well as for Hodgkin's disease (see Table 1).

In 1992, Irvine and Davies [15] reported results from a proportional mortality study among British pilots. The distribution of causes of deaths in this group and the British general population was compared. The study included 411 deaths among pilots serving or retired from British Airways during 1966 and 1989. They reported a small excess of all cancer combined (PMR = 1.31) and a reduced risk for circulatory and respiratory disease. The risk of lung cancer was not increased among the pilots, but a small excess was observed for malignant melanoma (6 cases), colon cancer (15 cases) and brain cancer (9 cases).

In 1990, Vagerö et al. [16] conducted a proportional mortality study based on cancer registry data in England, Wales and Sweden and found an increased percentage of malignant melanoma in pilots. An increased (recreational) exposure to UV radiation among pilots was supposed to be a potential cause of this observation.

Cohort studies

In 1990, Band et al. [17] reported results from a small cohort study among all male pilots employed by CP Air, Canada, since 1950. The study population included 918 eligible pilots, of whom 630 were still active at the end of the follow-up in October 1988. The identification of the cohort was done through company records, and the follow-up was successful for 97.6% of the employees. Standardised mortality ratios (SMR) and standardised incidence ratios (SIR) were used to compare mortality as well as cancer incidence of the cohort with that of the general population. Some 71 pilots had died by the end of the follow-up, and 57 incident cancer cases were ascertained. Statistically significant increased mortality rates were observed for aircraft accidents, for rectal cancer (SMR = 4.35) and for brain tumour (SMR = 4.17). The cancer incidence rates were significantly increased for non-melanoma skin cancer (SIR = 1.59), for Hodgkin's disease (SIR = 4.54) and for brain tumour (SIR = 3.45). Furthermore, non-significantly increased incidences were observed for melanoma, rectum and prostate cancer. However, all rate estimates were based on small numbers, which the authors regarded as the principal limitation of the study.

Recently, Band et al. [18] reported results from a larger cohort of Air Canada pilots. All male pilots who were employed for at least 1 year since 1950 and until 1992 were included in this study. These 2740 pilots contributed some 62 000 person years (PY) of observations to the study. The methods of data collection and statistical analysis were similar to those of their previous investigation in 1990 [13]. Decreased mortality rates were observed for all causes of death, for all cancers (SMR = 0.61) and for all non-cancer diseases combined. Similar to the previous study, there was a significantly increased mortality from aircraft accidents (SMR = 26.57). However, no particular cancer was associated with a significant increase in the mortality rates. In contrast, the mortality of lung cancer was much lower than expected (SMR = 0.25). The incidence rates were decreased for all site-specific cancers combined (SIR = 0.71), for rectal cancer (SIR = 0.42), lung cancer (SIR = 0.28) and bladder cancer (SIR = 0.36). Significantly increased incidence rates were observed for prostate cancer (SIR = 1.87) and for acute myeloid leukaemia (SIR = 4.72). Non-significant increases were seen for malignant melanomas, brain tumours and for all types of leukaemia combined as well as for non-chronic lymphoid leukaemias. The authors concluded that in particular leukaemia incidence and mortality should be followed up more closely.

In 1993, Kaji et al. [19] performed a cohort study among 2327 cockpit crew members registered at Japan Airlines between 1952 and 1988. The mortality rates of the crew members were compared to those of the general Japanese population using SMRs. By the end of the follow-up, only 2.5% (59 persons) of the cohort individuals had died. The authors reported a much lower overall SMR for the pilots (SMR = 0.66). They found differences in some cause-specific mortality rates: mainly those due to accidents were increased (SMR = 2.43). Death rates from cancer were similar to those of the general population (SMR = 0.87), while deaths from coronary heart diseases were reduced. Due to the small numbers details on specific types of cancer were not reported. The investigators may have faced particular difficulties with the follow-up in this study.

In 1996, Grayson and Lyons [21] investigated cancer incidence in the US Airforce aircrew. This cohort study included all men who had worked for the Airforce for at least 1 year between January 1975 and December 1989, thus including more than 200 000 persons. Cancer incidence was compared to the SEER standard population data (US cancer registries) and among two subpopulations (aircrew vs other officers). Some information on job history was available but not utilized for this analysis. Overall, the age-adjusted cancer rate among the aircrew was slightly but significantly elevated (SIR = 1.19). The authors also reported a significantly elevated SIR for skin neoplasms and urinary bladder cancers (compared with SEER rates). Decreased SIRs were observed for Hodgkin's disease. None of the other cancers showed significant differences. Interestingly, brain tumour and leukaemia rates were slightly (but not significantly) lower than in the general population. Relative to other (non-flying) officers, the overall cancer rates were significantly increased among the aircrews (RR = 1.31). Most site-specific cancer rates were slightly increased for the aircrew, with significant elevations for testis and urinary bladder cancer.

Similar to the findings of Irvine and Davies [15] with regard to proportional mortality rates, an excess of total cancer incidence was found in this study. However, the excess rates for cancers of the colon, rectum and brain and for leukaemia seen in other studies could not be confirmed. Up to now, the study by Grayson and Lyons [21] has been the only one using internal comparisons, which is likely to decrease the effects of confounding factors such as socioeconomic status. However, there may be manifold differences between airforce and civil pilots. The authors did not comment on e.g. flight hours or years in service of the cohort members. Furthermore, they noted that the aircrew cohort was relatively young.

In this cohort a nested case-control study on brain tumours [22] was carried out to evaluate the risk associated with the exposure to ionising and non-ionising radiation (Table 3). All brain cancer cases of the total cohort were included and compared with matched controls. Exposure assessment was done using a job-exposure matrix for electromagnetic fields and dosimetry records for ionising radiation. However, such records were available for only 3% of the cohort members. Pilots were designated as possibly exposed to electromagnetic fields, but it has not clearly been stated in the publication whether ionizing radiation

doses were assigned to them. There was an overall significantly increased odds ratio (OR) for exposure to low-frequency electromagnetic fields (OR = 1.28) and to radiofrequency/microwave fields (OR = 1.39), but no association of brain tumours with exposure to ionising radiation (OR = 0.56). In order to address the brain cancer risk of the aircrew directly, a further evaluation [23] compared cases among aircrew with cases among the non-flight personnel. The unadjusted OR was 1.77 and decreased to 1.22 after adjustment for socio-economic status. This fact made the authors conclude that differences in social status may also have confounded previous positive study results.

In Finland, a cohort study was recently performed among 1577 female and 187 male cabin attendants who started working for Finnair between 1940 and 1992 and were still alive in 1967 [20]. A statistically significant excess of breast cancer (SIR = 1.87) and bone cancer (SIR = 15.10) was observed among the female employees. The breast cancer risk was most prominent 15 years after recruitment. The risk of leukaemia and skin melanoma was non-significantly increased. The authors concluded that ionising radiation during flights might contribute to the cancer risk. However, the radiation doses of cabin attendants seemed to be too small to account entirely for the observed excess risk provided that present risk estimates for radiation effects are valid for cosmic radiation. The potential confounding influences of reproductive factors such as late first birth and low parity were considered in the discussion.

In a letter, Lynge [24] reported an increased risk of breast cancer incidence among Danish female cabin attendants on the basis of cancer registry data. The non-significant SIR was 1.61, thus higher than in social class I (OR 1.4). The overall numbers, however, were small.

Discussion and conclusions

In any PMR study only the relative distribution of causes of death is compared. Neither age nor duration of follow-up are taken into account. Studies of proportional mortality can thus only indicate possible differences in the distribution of causes of death. The cohort studies performed so far have had different limitations, mainly due to the high survival probability and the limited exposure assessments performed. The young age of the cohort members makes it difficult to study age-dependent health effects such as cancer. With the exception of one study [21], no internal comparisons have been made, thus leaving a large number of potential confounders not taken into account. There is a lack of exposure assessment (e.g. dosimetry of ionising and other radiations) in all current studies except the one carried out by Grayson [22].

The cohort studies show a very high healthy-worker effect and an increased risk of aircraft accidents. The results for cancer mortality are inconsistent: only brain tumours appear to be slightly elevated in most of the studies. The overall cancer rates are sometimes below, sometimes above

Table 4 Estimated number [illegible]

Country	Study period begins	Airlines[a]	Cockpit estimates	Cabin crew estimates
Denmark	1946 (cockpit) 1950 (cabin)	SAS	2 400	5 [illegible]
Finland	1967	Finnair	750	2 000
Germany	[illegible]	Lufthansa	[illegible]	[illegible]
Greece	1965	Olympic	500	1 000
Iceland	1956	Icelandair	460	>1 000
Italy	1965	Alitalia	2 212	[illegible]
Netherlands	1960	KLM	5 000	12 000
Norway	1946 (cockpit) 1950 (cabin)	SAS	3 800	5 600
Sweden	[illegible]	SAS		[illegible]
Great Britain[c]		British Airways		
Total			21 222	47 544

[a] Main airline included in the study
[b] No details known yet
[c] Planning to contribute data to joint analysis

average. Mainly because of the very small number of cases no clear picture has evolved concerning leukaemia, a type of cancer that is known to be associated with ionising radiation.

The studies of cancer incidence do not yet yield a conclusive picture. Various site-specific cancers with increased incidence in one study did not show comparable increases in other investigations. The finding of elevated breast cancer risk among cabin attendants deserves further attention, but it probably cannot be related to occupational risk factors only. The authors of all cited papers interpret their results with great caution and urge for further investigations of larger cohorts.

Future studies will have to consider comparisons with other than the general population and should be based on data including exposure measurements and dose calculations or at least the duration of employment of the cohort members. More reliable individual information on job history, lifetime flight-hours and routes flown as well as on potential confounders – in particular, the reproductive history of the female flight crew – will help to estimate cancer and other health risks of pilots and flight attendants more precisely.

In nine European countries new studies are under way or planned to investigate the cancer risk among aircrews further. A new British study has just been completed. The Nordic countries – Finland, Sweden, Denmark, Norway, Iceland – are currently performing an incidence study (results expected in late 1998) and are also participating in a joint European cohort mortality study. This project is supported by the BIOMED 2 programme of the European Commission and aims at homogenizing the study design of the national studies and facilitating a pooled analysis of the data. Each country will perform their cohort investigation on the basis of a common core protocol. Through the combined analysis, this overall cohort will be the most powerful to date to evaluate late effects associated with these occupations. The exposure assessment will be based

Table 5 Power calculations. European cohort mortality study (power 80%, α = 5%) based on data in Table 4 taking the age distribution into account, study period 1960–1996 with varying entry dates: (i) external comparison (SMR) with population mortality rates, internal comparison (RR) with 50% of cohort in "low" and 50% in "high" radiation exposure group

Cause of mortality	Women			Men		
	n	Minimum detectable risk by type of comparison		n	Minimum detectable risk by type of comparison	
		External	Internal		External	Internal
All causes	2093	1.1	1.1	3410	1.1	1.1
All cancers	599	1.1	1.2	1056	1.1	1.2
Brain cancer	25	1.6	1.9	20	1.7	2.0
Colon cancer	30	1.5	1.8	40	1.5	1.7
Breast cancer	242	1.2	1.3			
Leukaemia	26	1.6	1.8	27	1.6	1.8

on occupational history data. The participating countries, study periods, and numbers of persons enrolled in the respective cohorts are given in Table 4. Power calculations as presented in Table 5 are based on a common follow-up period from 1960 to 1996. Among pilots, some 20 brain cancers and 27 leukaemia cases will be expected using the age distribution described. Similarly, 25 brain cancers, 26 leukaemias and 242 breast cancers are to be expected among the female flight attendants. Thus, for external (SMR) comparisons, risks of the order of 1.1 (all cancers), 1.6–1.7 (brain cancer), 1.6 (leukaemia) and 1.2 (breast cancer) can be detected with sufficient statistical power. Power calculations for relative risk (RR) estimations comparing two exposure groups (low versus high) are additionally presented in Table 5.

For the detection of even smaller risks that might be expected purely on the basis of current radiation risk estimations (e.g. a relative risk of 1.1–1.2 for leukaemia assuming a lifetime cumulative dose of 100 mSv for a pilot flying trans-Atlantic routes), the ongoing studies are not likely to have sufficient power. Nevertheless, important information on the overall impact of the specific occupational environment of aircrews will be gained and possibly also lead to a better understanding of the way different factors interact and influence health and disease among pilots and cabin attendants.

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References

1. O'Brien K, Friedberg W, Sauer HH, Smart DF (1996) Atmospheric cosmic rays and solar energetic particles at aircraft altitudes. Environ Intern 22 [Suppl 1] S9–S44
2. UNSCEAR (1988) Sources, effects and risks of ionizing radiation. Report to the General Assembly. United Nations Scientific Committee on the Effects of Atomic Radiation. United Nations, New York
3. Regulla D, Walter A (...) Review study of the exposure of ... all passengers ... crew members ... (EC Contract No 70-ET-0 22) GSF - National Research Center for Environment and Health, Munich
4. Wilson OJ, Young BF, Richardson CK (1994) Cosmic radiation doses received by Australian commercial flight crews and the implications of ICRP 60. Health Phys 66: 493–502
5. SSK (1997) Die Ermittlung der durch kosmische Strahlung verursachten Strahlenexposition des fliegenden Personals. Berichte der Strahlenschutzkommission (SSK) des Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit. 1. 2nd revised edn. Gustav Fischer, Stuttgart
6. Bagshaw M, Irvine D, Davies DM (1996) Exposure to cosmic radiation of British Airways flying crew on ultralonghaul routes. Occup Environ Med 53: 495–498
7. McCartney MA, Chatterjee BF, McCoy EC, Mortimer EA, Rosenkranz HS (1986) Airplane emissions: a source of mutagenic nitrated polycyclic aromatic hydrocarbons. Mutat Res 171: 99–104
8. Mustafa MG, Hassett CM, Newell GW, Schrauzer GN (1988) Pulmonary carcinogenic effects of ozone. Ann NY Acad Sci 534: 714–23
9. Ryan P (1991) Smoking and commercial airline flights in Europe. Eur J Cancer 27: 1348–1350
10. BEIR (1990) Health effects of exposure to low levels of ionizing radiation. (BEIR V report) National Research Council. Committee on the Effects of Ionizing Radiations. National Academy Press, Washington DC
11. IARC Study Group on Cancer Risk among Nuclear Industry Workers (1994) Direct estimates of cancer mortality due to low doses of ionising radiation: an international study. Lancet 344: 1039–1043
12. Cardis E, Gilbert ES, Carpenter L, Howe G, Kato I, Armstrong BK, Beral V, Cowper G, Douglas A, Fix J, Fry SA, Kaldor J, Lave C, Salmon L, Smith PG, Voelz GL, Wiggs LD (1995) Effects of low doses and low dose rates of external ionizing radiation: cancer mortality among nuclear industry workers in three countries. Radiat Res 142: 117–132
13. Hotberg A, Blonc C (1983) Age-specific morbidity among navy pilots. Aviat Space Environ Med 54: 912–918
14. Salisbury DA, Band PR, Threlfall WJ, Gallagher RP (1991) Mortality among British Columbia pilots. Aviat Space Environ Med 62: 351–352
15. Irvine D, Davies DM (1992) The mortality of British Airways pilots, 1966–1989: a proportional mortality study. Aviat Space Environ Med 63: 276–279
16. Vagero D, Swerdlow AJ, Beral V (1990) Occupation and malignant melanoma: a study based on cancer registration data in England and Wales and in Sweden. Br J Ind Med 47: 317–324
17. Band PR, Spinelli JJ, Ng VTY, Moody J, Gallagher RP (1990) Mortality and cancer incidence in a cohort of commercial airline pilots. Aviat Space Environ Med 61: 299–302
18. Band PR, Nhu Le ND, Fang R, Deschamps M, Coldman AJ, Gallagher RP, Moody J (1996) Cohort study of Air Canada pilots: mortality, cancer incidence, and leukemia risk. Am J Epidemiol 143: 137–143
19. Kaji M, Tango T, Asukata I, Tajima N, Yamamoto K, Yamamoto Y, Hokari M (1993) Mortality experience of cockpit crew members from Japan Airlines. Aviat Space Environ Med 64: 748–750
20. Pukkala E, Auvinen A, Wahlberg G (1995) Incidence of cancer among Finnish Airline cabin attendants, 1967–92. BMJ 311: 649–652
21. Grayson JK, Lyons TJ (1996) Cancer incidence in United States Air Force aircrew, 1975–89. Aviat Space Environ Med 67: 101–104
22. Grayson JK (1996) Radiation exposure, socioeconomic status, and brain tumor risk in the US Air Force: a nested case-control study. Am J Epidemiol 143: 480–486
23. Grayson JK, Lyons TJ (1996) Brain cancer, flying, and socioeconomic status: a nested case-control study of USAF aircrew. Aviat Space Environ Med 67: 1152–1154
24. Lynge E (1996) Risk of breast cancer is also increased among Danish female cabin attendants. BMJ 312: 253 (letter)